Logistics Needs for Potential Deep Space Mission Scenarios Post Asteroid Crewed Mission

Pedro Lopez Jr.*
NASA Johnson Space Center, Houston, TX 77058

The Asteroid Redirect Mission (ARM) is currently being explored as the next step towards deep space human exploration, with the ultimate goal of reaching Mars. Current technology dictates that such missions will require systems that can support humans for durations as long as 900 days. The design and planning for these missions should include the logistics and provisions required to sustain the crew, including their mass and volume.

This paper will provide the information needed to determine the logistics mass and volume required to sustain crew based on crew size, mission duration, and whether the environmental control life support system (ECLSS) is open or closed. Details on how the factors for the various logistics items were determined will also be provided. Results for potential mission scenarios will also be discussed. Opportunities for significant mass and volume reduction, identified through mass breakdown, will be provided, as well as potential threats that will need to be addressed to attain mission success.

* Aerospace Engineer, Advanced Mission Development Group, Technical Integration Office, Engineering Directorate/EA4.

Logistics Needs Assessment for 300, 600, and 900-Day Missions with Closed Loop ECLSS

Pedro Lopez

Agenda

- **Introduction**
- **Consumables Rate Assessment**
  - Water
  - Gases
  - Food
  - Crew Provisions
- **Logistics Needs Determination**
  - Total Mass/Volume for Each Scenario
  - Opportunities and Threats
- **Conclusions**

Introduction

- **Compared logistics studies performed by DSH, HAT and CAT to select rates to be used for each consumable item**

- **Assessed logistics mass required to sustain the following cases:**
  - 300, 600, and 900-day, closed-loop ECLSS missions
    - 3, 4, and 6 crew
- **Included volume required for logistics mass, with packaging**
- **Compared logistics needed against Standard Cygnus-type Logistics Module delivery capability to each destination**
- **Study did not include mass for spares, science, radiation protection, etc.**

Water

Water Usage

Item	Units	Rate	Open/ Closed ECLS	Notes	CAT	HAT	DSH	DIFFERENCES
O2 Generation	kg per crewday	1	Closed	Orion/CCDev	Agree	Agree	0.3402	DSH rate heritage not clear
H2O Drink	kg per crewday	2	Both	Orion/CCDev	Agree	Agree	4.3	Overall water value from DSH; ISS heritage reported
H2O Food Rehydration	kg per crewday	0.5	Both	Orion/CCDev	Agree	Agree		
H2O Medical	kg per crewday	0.05	Both	Orion/CCDev	Agree	Agree		
H2O Hygiene	kg per crewday	0.4	Both	Orion/CCDev	Agree	Agree		
H2O Flush	kg per day	0.25	Both	Orion/CCDev	Agree	Agree		

Water Recovery (Closed Loop)

Item	Units	Rate	Percent Recoverable	Notes	CAT	HAT	DSH	DIFFERENCES
Sabatier	kg per crewday	0.5	-	50% of O2 loss	Agree	Agree	-	
Crew Latent	kg per crewday	1.87	100	Orion/CCDev	Agree	1.93	-	HAT rate heritage not clear
Urine	kg per crewday	1.49	85	Orion/CCDev	Agree	Agree	-	
Flush	kg per day	0.25	85	Orion/CCDev	Agree	Agree	-	
H2O Hygiene	kg per crewday	0.4	100	Carried by HAT	-	Agree		Included in total water recovery
H2O Medical	kg per crewday	0.05	100	Carried by HAT	-	Agree		Included in total water recovery

Water Container

Item	Capacity (L)	Empty Mass (kg)	Volume (m^3)	Notes	CAT	HAT	DSH	DIFFERENCES
Rodnik Tank	210	35	0.21	ISS Heritage	Agree	Agree	-	

- **Water usage rate of 3.0125 kg and 4.0125 kg for open and closed-loop ECLS, respectively**
- **Water recovery of 4.140kg by combining CAT and HAT rates**
- **Rodnik tanks used for containment**

Gases

Gases

Item	Units	Rate	Open/ Closed ECLS	Notes	CAT	HAT	DSH	DIFFERENCES
O2 Metabolic	kg per crew/day	0.82	Open	Orion/CCDev	Agree	Agree	0.272	
Swing Bed Ullage - O2	kg per day	0	Open	Orion CO2 removal not used	Agree	Agree	-	
Swing Bed Ullage - N2	kg per day	0	Open	Orion CO2 removal not used	Agree	Agree	-	
Cabin Air Leakage	kg per day	0.00454	O2/N2 for Open, N2 for closed	Engineering Est.	Agree	Agree		Based on doubling test rate, still order of magnitude lower than Node requirement; 21% O2, 79% N2
Cabin Air Leakage - Orion	kg per day	0.00908	O2/N2 for Open, N2 for closed	Orion	Agree	Agree	-	21% O2, 79% N2
N2/O2 Tank Ullage	kg per tank	0.5	Both	Orion/CCDev	Agree	Agree	-	

Gas Container

Item	Capacity (kg)	Empty Mass (kg)	Volume (m^3)	Notes	CAT	HAT	DSH	DIFFERENCES
COPV - O2	38.1	74.8	0.39	ISS Heritage	Agree	Agree	-	
COPV - N2	28.7	74.8	0.39	ISS Heritage	Agree	Agree	-	

- **O_2 consumption and O_2 leakage covered by O_2 generation on closed-loop**
- **Swing beds only used in open-loop**
- **COPV tanks used for containment**

Food/Crew Provisions

Food/Crew Provisions

Item	Units	Rate	Notes	CAT	HAT	DSH	DIFFERENCES
Food	kg per crew/day	1.831	BVAD Table & ISS experience	Agree	Agree	1.663	DSH based on ISS
Food Containment Bags	kg per kg food	0	Included above	Agree	Agree	Agree	
Waste Collection - Fecal Canisters	kg per day	0.9	per JSC/EC, Orion values	Agree	Agree	-	DSH assumes using collection bags at 0.23 kg/crew/day
Waste Collection - Urine Prefilter	kg per day	0.25	per JSC/EC, Orion values	Agree	Agree		DSH assumes prefilters part of WHC
Fecal/Urine Collection Bags (contingency)	kg per crewday	0	Reuse contingency waste collection capability in Orion	Agree	Agree	-	
Personal Hygiene Kit	kg per crew	1.8	ISS value; used for every six months	Agree	Agree	Agree	
Hygiene Consumables	kg per crewday	0.079	Match Orion WCS Supplies Value	Agree	Agree	0.075	Minor difference
Clothing (No Laundry)	kg per crewday	0.46	Match Orion Clothing and Crew Pref Value	Agree	Agree	0.33	DSH rate heritage not clear
Recreation & Personal Stowage	kg per crew	25/50	25kg for up to 1yr; 50kg for more than 1 yr	Agree	Agree	50	DSH uses constant mass allocation
Wipes (housekeeping)	kg per crewday	0.25	AES trash team / ISS historical data	Agree	Agree	0.3	Minor difference
Trash Bags	kg per crewday	0.011	AES trash team / ISS historical data	Agree	Agree	0.05	DSH based on ISS
Operational Supplies	kg per crew	20/25	20kg for up to 1yr; 25kg for more than 1 yr	Agree	Agree	20	DSH uses constant mass allocation
Survival kit	kg per crew	0	Reuse Orion Items	Agree	Agree		
Sleep Accomodations	kg per crew	0	Reuse Orion Sleep Restraints	Agree	Agree	9	
Health Care Consumables	kg per crewday	0.09	AES trash team / ISS historical data	Agree	Agree	-	
Medical/Surgical/Dental	kg	0	Assume reuse items included in 62kg misc kit on Orion or booked in dry mass	Agree	Agree	-	
Emergency Breathing Apparatus	kg per crew	0	Reuse Orion Items	Agree	Agree	-	

- **Some differences between CAT/HAT and DSH**
- **Personal hygiene, personal stowage, and operational supplies rate used as factor based on mission duration**

Food/Crew Provisions - Containment

Food/Crew Provisions Containment

Item	Units	Rate	Notes	CAT	HAT	DSH	DIFFERENCES
CTB Mass, Empty	kg	1.56	ISS	Agree	2	-	
CTB Mass Capacity	kg	11.44	ISS average experience	Agree	18	-	HAT based on ISS maximum
CTB Volume	m^3	0.053	ISS	Agree	Agree	-	

- **Food/crew provisions carried in ISS Cargo Transfer Bags (CTBs)**

Logistics Assessment Overview

- **Methodology**
  - Collect ISS mass and volume usage data for crew consumables
  - Apply previous studies' assumptions along with ISS methodology to determine reasonable, consistent Water, Gas, Food, and Crew provision logistics necessary to sustain a mission

- **General Assumptions**
  - Used the following for leakage calculations:
    - Orion + 4 Modules (habitation module, two Logistics Module, and Deep-Space Module) for missions to Deep Space (EML2)
      - Additional LMs not included, will only affect N2 lost since O2 leakage is covered by closed-loop ECLSS
  - Regenerative ECLSS via urine processor, condensate recovery, and Sabatier for closed-loop case
  - Launch/entry items (e.g., suits, etc.) not included, only consumables and crew provisions (which includes waste management)
  - Logistics delivered via standard Cygnus-type to EML2
    - 3.2t delivery capability to EML2

Logistics Study – Executive Summary

- **Study Summary**
  - Assessed logistics mass required to sustain the following cases:
    - 300, 600, and 900-day, closed-loop ECLSS missions (3, 4, and 6 crew)
- **Closed-loop ECLSS results in surplus of O_2 and H_2O; however, some of each is required to kick-start the system**
  - Assumed adding 25kg of O_2 and H_2O each, along with tanks (when needed)
- **Logistics mass required for 300-day missions to EML2 for up to 4 crew with closed-loop ECLSS can be delivered on two LMs (up to 4,843.8kg occupying 19.5m^3 of volume)**
  - 4-crew case results in ~1570kg available for other items such as spares
  - 6-crew case would require a third LM
- **600-day missions for up to 4-crew would require three LMs**
  - **4-crew case results in only ~170kg available for other items such as spares, would need additional LM**
  - **6-crew case would require 5 LMs (13,651.5kg occupying 54.89m^3 of volume)**
- **900-day missions would require 4, 5, and 7 LMs for the three cases assessed, respectively**

Total Mass/Volume Calculation (3-crew, 300-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.87	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	8.31	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	1647.9	
Crew Provisions	1146	
Total	**2803.1**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	327.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	427.4	
Total	**904.0**	**85**
		25kg O2, 25kg H2O + Rodnik tank added to kick-start system

Grand Total =	**3792.1**	Kg	***Requires 2 LMs due to mass***
Cygnus Capability to EML2=	**3206**	Kg	

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
300 Day, 3 Crew	3120.9	3495.4	13	269	**14.26**

Volume of 1 CTB: 0.053

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume			
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**
COPV (O_2)	0.39	1	0.39
COPV (N_2)	0.39	1	0.39
			0.78

Total Volume	**15.3**	m^3	***Requires 1 LM due to volume***
Cygnus Capability to EML2	**18.9**	m^3	

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (4-crew, 300-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.87	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	8.31	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	2197.2	
Crew Provisions	1413	
Total	**3619.4**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	436.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	553.8	
Total	**1139.4**	**85**
		25kg O2, 25kg H2O + Rodnik tank added to kick-start system

Grand Total =	**4843.8**	Kg
Cygnus Capability to EML2=	**3206**	Kg

Requires 2 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
300 Day, 4 Crew	4046.2	4531.7	13	349	**18.50**

Volume of 1 CTB: 0.053

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks			
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**
Water	0.21	1	**0.21**

Water to kick-start system

ISS NORS Tank Volume			
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**
COPV (O_2)	0.39	1	0.39
COPV (N_2)	0.39	1	0.39
			0.78

Total Volume	**19.5**	m^3
Cygnus Capability to EML2	**18.9**	m^3

Requires 2 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (6-crew, 300-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.87	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	8.31	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	3295.8	
Crew Provisions	1947	
Total	**5252.0**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	654.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	806.5	
Total	**1610.1**	**85**
		25kg O2, 25kg H2O + Rodnik tank added to kick-start system

Grand Total =	**6947.1**	Kg	***Requires 3 LMs due to mass***
Cygnus Capability to EML2=	**3206**	Kg	

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
300 Day, 6 Crew	5896.8	6604.4	13	509	**26.98**

Volume of 1 CTB: 0.053

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume			
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**
COPV (O_2)	0.39	1	0.39
COPV (N_2)	0.39	1	0.39
			0.78

Total Volume	**27.97**	m^3	***Requires 2 LMs due to volume***
Cygnus Capability to EML2	**18.9**	m^3	

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (3-crew, 600-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	13.33	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	3295.8	
Crew Provisions	2292	
Total	**5601.1**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	654.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	853.3	
Total	**1582.1**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total = **7343.1** Kg

Cygnus Capability to EML2= **3206** Kg

Requires 3 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
600 Day, 3 Crew	6241.8	6990.8	13	538	**28.51**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume **29.5** m^3

Cygnus Capability to EML2 **18.9** m^3

Requires 2 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (4-crew, 600-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	13.33	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	4394.4	
Crew Provisions	2826	
Total	**7233.7**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	872.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	1106.0	
Total	**2052.8**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total = **9446.3** Kg

Cygnus Capability to EML2= **3206** Kg

Requires 3 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
600 Day, 4 Crew	8092.4	9063.5	13	698	**36.99**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume **37.98** m^3

Cygnus Capability to EML2 **18.9** m^3

Requires 3 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (6-crew, 600-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	13.33	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	6591.6	
Crew Provisions	3894	
Total	**10498.9**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	1308.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	1609.9	
Total	**2992.7**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total = **13651.5** Kg

Cygnus Capability to EML2= **3206** Kg

Requires 5 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
600 Day, 6 Crew	11793.6	13208.8	13	1017	**53.90**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume **54.9** m^3

Cygnus Capability to EML2 **18.9** m^3

Requires 3 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (3-crew, 900-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	19.75	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	4943.7	
Crew Provisions	3438	
Total	**8401.5**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	981.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	1279.2	
Total	**2335.0**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total = **10896.3** Kg

Cygnus Capability to EML2= **3206** Kg

Requires 4 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
900 Day, 3 Crew	9362.7	10486.2	13	807	**42.77**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume **43.76** m^3

Cygnus Capability to EML2 **18.9** m^3

Requires 3 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (4-crew, 900-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	19.75	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	6591.6	
Crew Provisions	4239	
Total	**10850.4**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	1308.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	1656.7	
Total	**3039.5**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total = **14049.7** Kg

Cygnus Capability to EML2= **3206** Kg

Requires 5 LMs due to mass

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
900 Day, 4 Crew	12138.6	13595.2	13	1046	**55.44**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume **56.43** m^3

Cygnus Capability to EML2 **18.9** m^3

Requires 3 LMs due to volume

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Total Mass/Volume Calculation (6-crew, 900-day, closed loop)

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	0.0	100% condensate & 85% urine/flush recovery
Oxygen (Metabolic)	0	Obtained from water
Oxygen (Leakage & Ullage)	0.00	Reduce with better module and vehicle volumes
Nitrogen (Leakage & Ullage)	19.75	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	9887.4	
Crew Provisions	5841	
Total	**15748.2**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (0)	0	Each Rodnik is ~35 kg
O_2 Tanks (0)	0	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	1962.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	2414.9	
Total	**4451.7**	**159.8**
		25kg O2 + COPV, 25kg H2O + Rodnik tank added

Grand Total =	**20359.6**	Kg	***Requires 7 LMs due to mass***
Cygnus Capability to EML2=	**3206**	Kg	

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
900 Day, 6 Crew	17690.4	19813.2	13	1525	**80.83**

Volume of 1 CTB: 0.053

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks				
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**	
Water	0.21	1	**0.21**	Water to kick-start system

ISS NORS Tank Volume				
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**	
COPV (O_2)	0.39	1	0.39	O2 to kick-start system
COPV (N_2)	0.39	1	0.39	
			0.78	

Total Volume	**81.82**	m^3	***Requires 5 LMs due to volume***
Cygnus Capability to EML2	**18.9**	m^3	

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Logistics Results – Summary

DOCKED OPS DURATION	Crew Size	ECLSS Type	LM Capacity	Logistics Mass Required	Logistics Volume	Minimum # of LM Needed
300 days	3	Closed	3206kg/18.9m^3	3792.1kg	15.3 m^3	2
300 days	4	Closed	3206kg/18.9m^3	4843.8kg	19.5 m^3	2
300 days	6	Closed	3206kg/18.9m^3	6947.1kg	27.97 m^3	3
600 days	3	Closed	3206kg/18.9m^3	7343.1kg	29.5 m^3	3
600 days	4	Closed	3206kg/18.9m^3	9446.3kg	37.98 m^3	3
600 days	6	Closed	3206kg/18.9m^3	13651.5kg	54.9 m^3	5
900 days	3	Closed	3206kg/18.9m^3	10896kg	43.76 m^3	4
900 days	4	Closed	3206kg/18.9m^3	14050kg	56.43 m^3	5
900 days	6	Closed	3206kg/18.9m^3	20360kg	81.8 m^3	7

Backup

Opportunities and Threats

- **Water**
  - (O) Tanks mounted outside pressurized volume could save 0.210 m^3 each
  - (O) Precise drinking/hygiene/food rehydration and medical allocation could reduce mass by 0.75 kg/c/d
    - Flush amount the same, just calculated in separate location of models
- **Gases**
  - (O) Tanks mounted outside pressurized volume could save 0.39 m^3 each
  - (O) This study utilized O_2 and N_2 for leakage, ISS utilizes air
    - Air less complex/expensive to handle
  - Potential safety concern with burst or large leak in tank
    - Ensure pressure relief valve capability
- **Crew Provisions**
  - (O) ISS wipes and clothing rates of 0.153 and 0.196 kg/c/d, respectively
    - **Savings of 1949kg for 900-day, 6-crew**
  - Toilet different by design
    - (O) ISS model uses KTOs at 0.48 kg/d
      - **126kg, 252kg, and 378kg savings with KTOs for 300, 600, and 900-day missions, respectively**
    - (O or T) Reconcile urine pre-treat filter calculation
  - (O or T) Reconcile category differences between previous Exploration model & ISS methodology
- **Volume**
  - (T) Packing density needs thorough review with Logistics Team
    - Actual individually packing could produce slightly higher volume

Water

- **Assumptions**
  - Rodnik tanks within pressurized volume of Logistics Module
    - Major difference against ISS – Impacts to pressurized cargo volume
  - Silver biocide water with 3 year shelf life

- **Consumption (See figure on next two charts)**
  - Consistent with MPCV and CCDev exploration assumptions
    - Slightly more conservative
      - Deviation from ISS
        - » 2.2 L/Crewman/Day Drinking/Hygiene/Food
        - » No medical allowance
        - » 0.3 L/Crewman/Day Flush*
        - » 75% water recovery rate vs 85%

Open-Loop ECLSS

2.9 L Drinking/Hygiene/Food →	Crew Latent → 1.87 L
0.35 L Metabolic Water →	Urine → 1.49 L
0.50 L Water in Food →	Feces Water → 0.19 L
0.05 L Medical →	Wet Trash → 0.25 L
0.0625 L Flush† →	Flush → 0.0625 L
3.0125 L Resupplied Water	Water Lost 3.8625 L
0.85 L Unaccounted Water	

† 0.25 L Water once a day flush for 4 Crew
- ISS Assumes 0.3 L/flush/crew/day

- Does not take into account Payload water
  - ISS uses 1.27 L Resupply of which 0.82 L is recovered and 0.45 L is lost

Closed-Loop ECLSS

1.0 L Water for O_2 Generation →
2.9 L Drinking/Hygiene/Food →
0.35 L Metabolic Water →
0.50 L Water in Food →
0.05 L Medical →
0.0625 L Flush† →

4.0125 L Resupplied Water
0.85 L Unaccounted Water

H_2 and O_2 → 0.5 L
Sabatier → 0.5
Crew Latent → 1.87 L
Urine → 1.49 L
Feces Water → 0.19 L
Wet Trash → 0.25 L
Flush → 0.0625 L

Recoverable Water 3.9225 L
Water Lost 0.94 L

† 0.25 L Water once a day flush for 4 Crew
- ISS Assumes flush/crew/day

Added 0.40 L Hygiene and 0.05 L Medical to recoverable water as recommended by DSH

- Does not take into account Payload water
  - ISS uses 1.27 L Resupply of which 0.82 L is recovered and 0.45 L is lost

Gases

- **Assumptions**
  - Provide N_2 and O_2 to cover leakage
    - No oxygen required for crew consumption for closed-loop cases, created using water via O_2 generator
  - COPV (ISS NORS Tank) inside pressurized volume – impacts cargo volume
    - Empty mass of 74.8kg; capacity of 38.1kg O_2 or 28.7kg N_2
  - Calculated leak rate based on ISS Engineering experience, and considers:
    - Nominal and anomalous leakage
  - Includes tank ullage (closed-loop and open-loop) and swingbed ullage (open-loop only)
  - Calculation includes leakage during untended periods during one year for missions shorter than 365 days

- **Consumption**
  - O2 crew consumption rate of 0.82 kg/crew/day (open-loop)
  - Air Leakage estimated rate of 0.01 lbm/day (0.0045 kg/day) for a given module
    - Engineering estimate*
    - Little over double for Orion (0.00908 kg/day)
  - For leakage calculations assume:
    - MPCV + 2 modules (Node and one Logistics Module) for 30/60-day missions
    - MPCV + 3 modules (Node, Deep Space, and one Logistics Module) for 180/360/540-day missions

* ***Leakage Rate Estimation***
  - *Based upon ISS Node 1 specification (.117 lb/day) and test (.005 lb/day) leak rates*
  - *Doubling test rate but still stay order magnitude below requirement*
    - *Try not to be so conservative you can't verify*

Food

- **Assumptions**
  - Only use “single” CTB* for containment/storage

- **Mass per crewmember per day**
  - 1.831 kg for food, including sealed wrapping
    - Does not include Bulk Overwrap Bag (BOB) weight
      - ~60 grams each
    - Does not include containment/storage container
      - CTB weight factored in separately
        - » Single CTB + foam = 1.56 kg

*Conservative bag choice

Crew Provisions

- **Assumptions**
  - Provide clothes, comfort items, office supplies, waste and hygiene supplies, etc. for crew
  - Three categories
    - Per mission use (kg/crew)
    - Daily use per crew person (kg/crew/day)
    - Daily use for all crew (kg/day)

Per Mission Use (kg)					
Category	**Subcategory**	**Examples**	**60 Day Mass Per Crewmember (kg/Crew)**	**60 Day, 4 Crew Total (kg)**	**180 Day 4 Crew Total (kg)****
Crew Personal Items, One-time use, and Crew care Packages	Crew Care Packages*	Personal photos, personal T-shirts, books, keepsakes, Shoes, etc.	10.0	40	120
	Operational Supplies	Batteries, notebooks, office supplies, etc.	10.0	40	120
	Personal Hygiene Kit		1.8	7.2	21.6
		Total	21.8	**87.2**	**261.6**

* Some personal items already in MPCV

** Based on ratio (kg/day) for the 60 day stay

Crew Provisions

- **Some notable differences between ISS and Exploration modeling**
  - ISS model uses 0.153 kg/c/d for wipes
  - ISS model uses 0.196 kg/c/d for clothing

Daily Use per Crew Person (kg/crew/day)					
Category	**Subcategory**	**Examples**	**Mass Per Crewmember per day (kg/C/D)**	**60 Day, 4 Crew Total (kg)**	**180 Day 4 Crew Total (kg)**
Regularly consumed items	Hygiene consumables		0.079	19.0	56.9
	Health Care Consumables		0.09	21.6	64.8
	Wipes	Wet wipes, Household wipes, dry wipes	0.25	60.0	180.0
	Trash Bags		0.011	2.6	7.9
	Clothes	t-shirts, shorts, pants, socks, exercise clothes, etc.	0.46	110.4	331.2
		Total	0.89	**213.6**	**640.8**

Crew Provisions

- **Fecal canisters and urine pre-filter differ by toilet design from ISS**
  - ISS model uses KTOs at 0.48 kg/d
  - Urine pre-treat filter considered part of ISS WHC

Daily Use for All Crew (kg/day)					
Category	**Subcategory**	**Examples**	**Mass Per Day (kg/Day)**	**60 Day, 4 Crew Total (kg)**	**180 Day 4 Crew Total (kg)**
Waste Collection	Fecal Canisters		0.90	54.0	162.0
	Urine Pre-filter		0.25	15.0	45.0
		Total	1.15	**69.0**	**207.0**

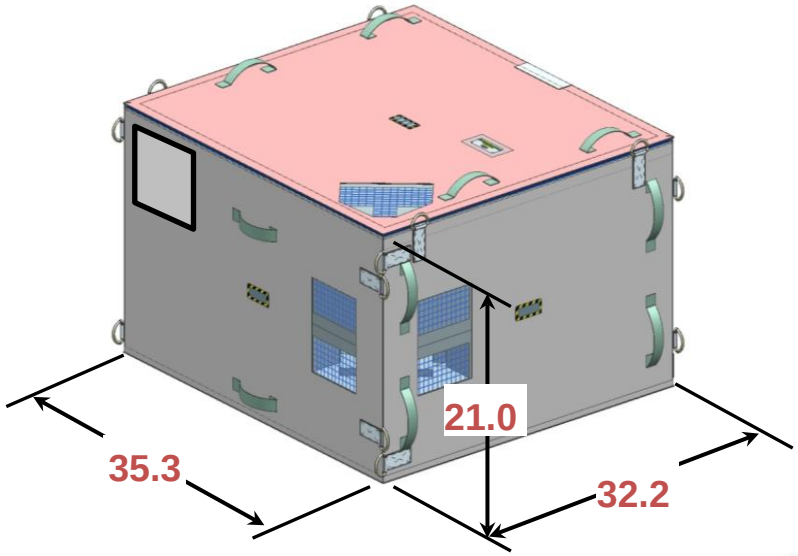
Total Volume Calculation

- **Assumptions**
  - Apply single CTB for conservatism and simplicity
    - Final packing efficiencies could be obtained
  - ISS average density from historical experience
  - Volume of 1 CTB = 0.053 m^3
  - Single CTB average packing density is 13 kg/CTBe

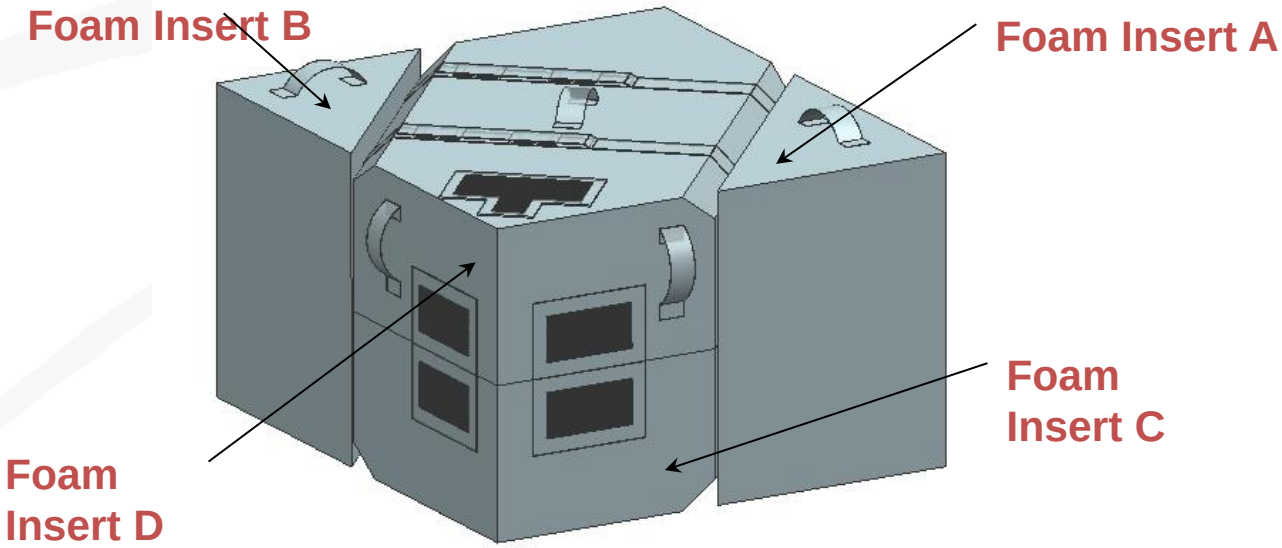
- **ISS packing experience defines "Customer Cargo"**
  - Customer cargo = (Usable Cargo) x (Packing Factor)
    - Usable cargo is the weight of the cargo item alone, no packing or FSE
    - ISS Packing factor = 12%

Backup for Consumable

M-01 Configuration

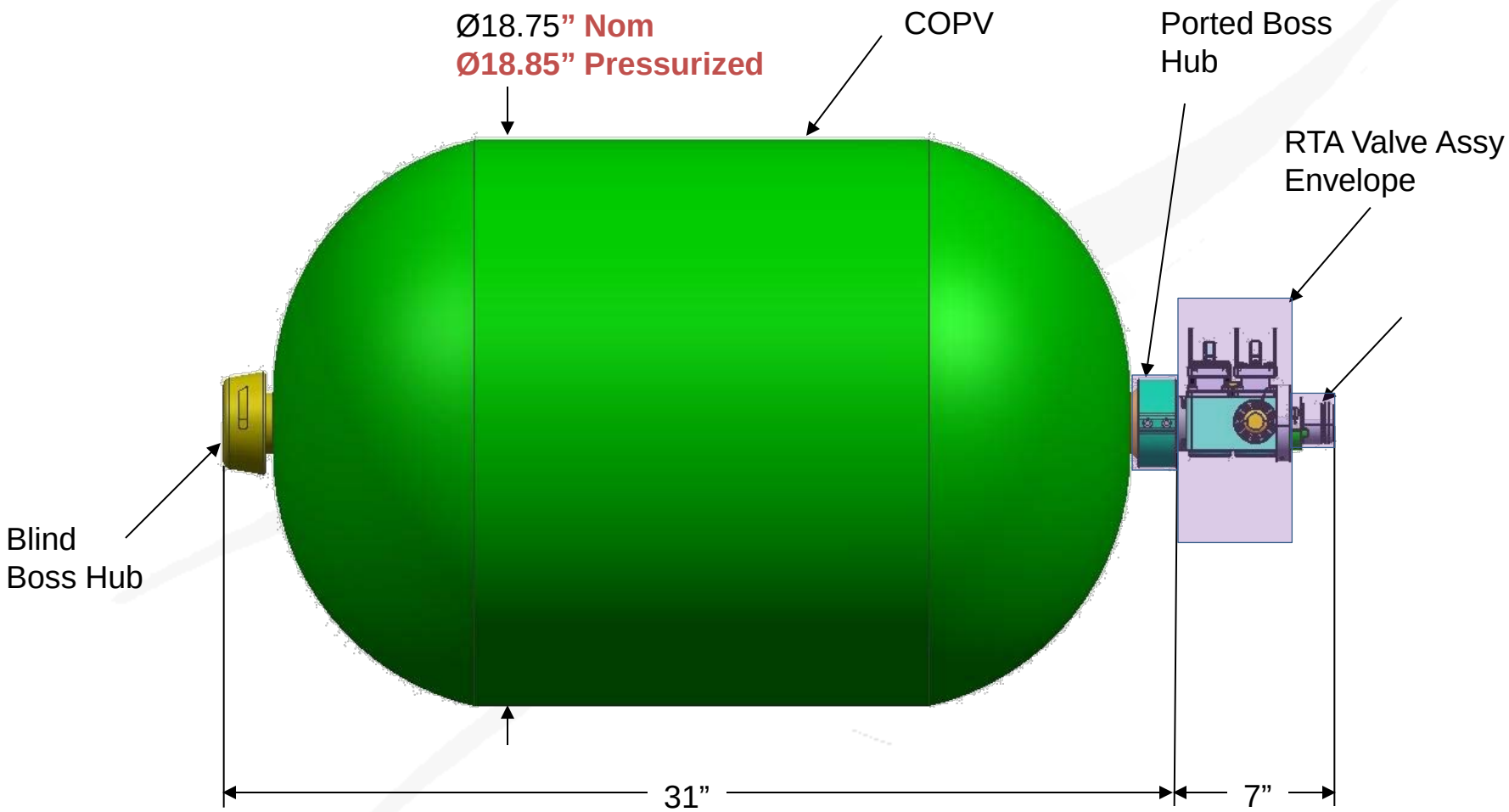


- Uses M-01 Bag dimensional envelope
- Same basic interfaces as M-01 bag
- Same zippered opening as M-01 bag
- Incorporates venting for excess gas buildup
- Utilizes cut Zotek F-30 foam inserts
- Center foam section can fit through tight diameter hatches
- Inserts wrapped in Beta Cloth to eliminate debris
- P/N 684-015302



Foam Inserts – VIA Not shown

RTA Dimensions



ISS Trash/Waste

- **Assumptions**
  - Account for Crew daily waste, Fecal waste, hardware, and packing material
  - Trash stored in CTBs, Jettison Stowage Bags (JSB), and KTOs
  - Whatever went up, must come down
    - Except for urine and condensate (Vented)
    - Rate equivalent to usage

- **Mass capacity for waste containers**
  - CTB = (Depends on available CTB size)
  - KTO = 11.5 kg
  - JSB = variable depending on content (i.e. H/W vs bubble wrap)
    - Range from 0.5kg to 20 kg

- **Volume capacity for waste containers**
  - Single CTB* = 0.0283 m^3
  - KTO = 0.0198 m^3
  - JSB = 0.0764 m^3

*Varies by chosen CTB

Logistics Needs Assessment for Mars Transit Vehicle 600-Day, 4-Crew (Round-Trip Duration)

Pedro Lopez

Logistics Study – Executive Summary

- **Study Summary**
  - Assessed logistics mass required on Mars transit vehicle to sustain crew (round-trip)
    - 600-day, 4-crew, closed-loop ECLSS mission
- **Logistics mass required for this mission scenario amounts to <u>8,614.9kg occupying 33.2m^3 of volume</u>**
  - Includes fluid consumables for contingency
- **Closed-loop ECLSS results in no O_2/H_2O required**
  - 30 days of open-loop margin provided for contingency
    - 361.5kg H_2O and 100.1kg O_2 , plus container mass
- **Identified potential opportunities and threats by analyzing mass breakdown**
  - Food represents 51% (~4,400kg) of total logistics
    - **Rate may be reduced via optimization of packaging**
  - CTBs represent ~11% (~930kg), fecal canisters represent ~6% (~540kg)
    - **Potential targets for optimization, could result in considerable mass savings**
  - Clothing represents ~6% (~530kg)
    - **Reusable clothing and/or addition of laundry system may result in mass savings**
      - **More significant savings with increased crew size and mission duration**
      - **Effect on water processing system needs to be determined**
  - Food expiration and water quality will be an issue due to mission durations
    - **Freezer(s) most likely required**
    - **Water quality monitoring**

Agenda

- **Introduction**
- **Assessment Overview**
- **Review of Opportunities and Threats**
  - Mass Breakdown
  - Food
  - CTBs
  - Fecal Canisters
  - Clothes
  - Other Opportunities/Threats
- **Review of Consumables Rates**
- **Logistics Needs Determination**
  - Total Mass/Volume
- **Conclusions**

- **Would like to thank the following for their inputs/advice:**
  - Molly Anderson and Imelda Stambaugh (EC)
  - Matt Simon, Chel Stromgren and Kandyce Goodliff (LaRC)
  - Eric Schultz (ISS)

Introduction

- **Assessed logistics mass required on Mars transit vehicle to sustain crew of 4 for 600 days (round-trip duration) based on closed-loop ECLSS**
- **Included volume required for logistics mass, with packaging**
- **Compared logistics needed against Standard Cygnus-type Logistics Module delivery capability to each destination**
- **Study did not include mass for spares, science, radiation protection, etc.**

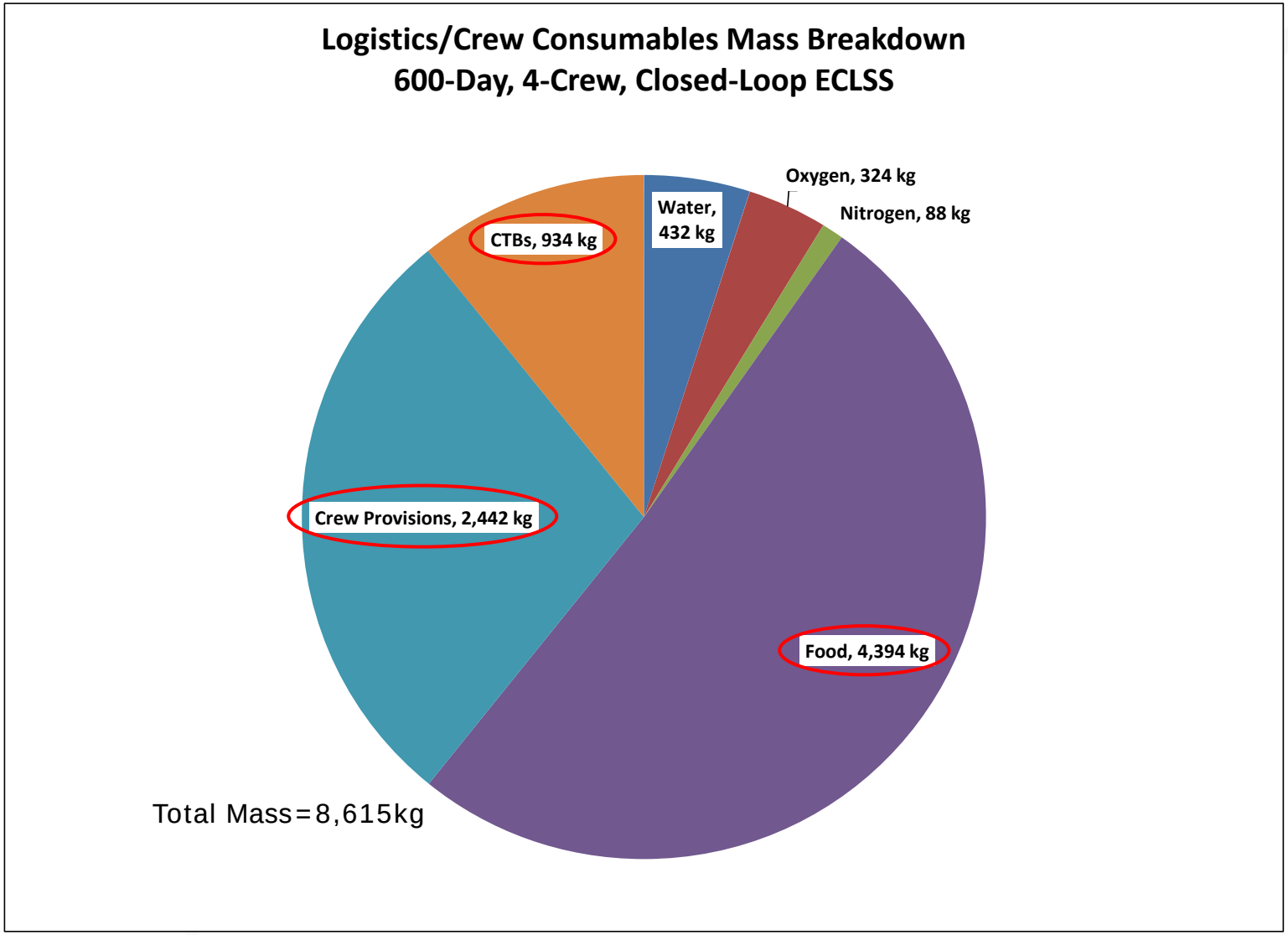
Logistics Assessment Overview

- **Methodology**
  - Collect ISS mass and volume usage data for crew consumables
  - Apply previous studies' assumptions along with ISS methodology to determine reasonable, consistent Water, Gas, Food, and Crew provision logistics necessary to sustain a mission
  - Coordinated all rate information with HAT to ensure consensus approach

- **General Assumptions**
  - Consumables calculated for 600 days nominal (closed-loop) + 30 days contingency (open-loop)
  - Used the following for leakage calculations:
    - Orion + 4 Modules (habitation module, two Logistics Module, and Deep-Space Module) for missions to Deep Space (EML2)
  - Regenerative ECLSS via urine processor, condensate recovery, and Sabatier for closed-loop case
  - Launch/entry items (e.g., suits, etc.) not included, only consumables and crew provisions (which includes waste management)
  - Logistics delivered via standard Cygnus-type to EML2
    - 3.2t delivery capability to EML2

Logistics Mass Breakdown

- **Food, CTBs and Crew Provisions represent majority of logistics**



Food (~4,400kg – 51% total logistics)

OPPORTUNITY

Food rate

- **Current study uses 1.831 kg/crewday based on BVAD Table and ISS experience**
  - Based on current packaging methods (each meal separately packaged)
  - Results in 4,394kg for this case

- **Metabolic requirement is 1.5kg/crewday**
  - ~0.33kg/crewday savings available via packaging optimization

- **Assuming ~0.2kg/crewday rate reduction via packaging optimization would result in ~480kg savings for this case**

- **Other packaging methods need to be explored to determine whether rate can be reduced**

Food (~4,400kg – 51% total logistics)

THREAT

Food Expiration

- **Food limited to ~one-year useful stored lifetime; longer duration missions require means to extend lifetime**
- **Freezer(s) possibly required, representing additional mass and volume**
- **Current case would require freezer with 5.6m^3 capacity**
  - Volume determined using 307kg/m^3 density for food required for 235 days (600-365 days)
- **Freezer required could result in ~1,200kg mass increase, occupying ~6m^3 of pressurized volume**
  - Ref: Mars Transit Habitat Sizing study (LaRC/M. Simon); based on Human Spaceflight book, crew accommodations chapter (400kg mass allocation occupying 2m^3 pressurized volume)

- **Longer duration missions would require more freezer volume**
  - 900-day, 4-crew would require ~12.8m^3 of freezer capacity (~2,500kg mass increase)

CTBs (~930kg – 11% of total logistics)

OPPORTUNITY

- **CTBs are designed to withstand launch loads while safely delivering a wide array of items**
  - Cargo densities as high as ~510 kg/m^3 (max load for full CTB, strapped)
  - Over-designed to deliver items such as food, clothing, hygiene/crew care, wipes, trash bags, etc.
    - Food density assumed at ~300 kg/m^3
- **Custom design of bags for lower density cargo would result in mass savings**
- **Concepts could be tested on cargo delivery to ISS**

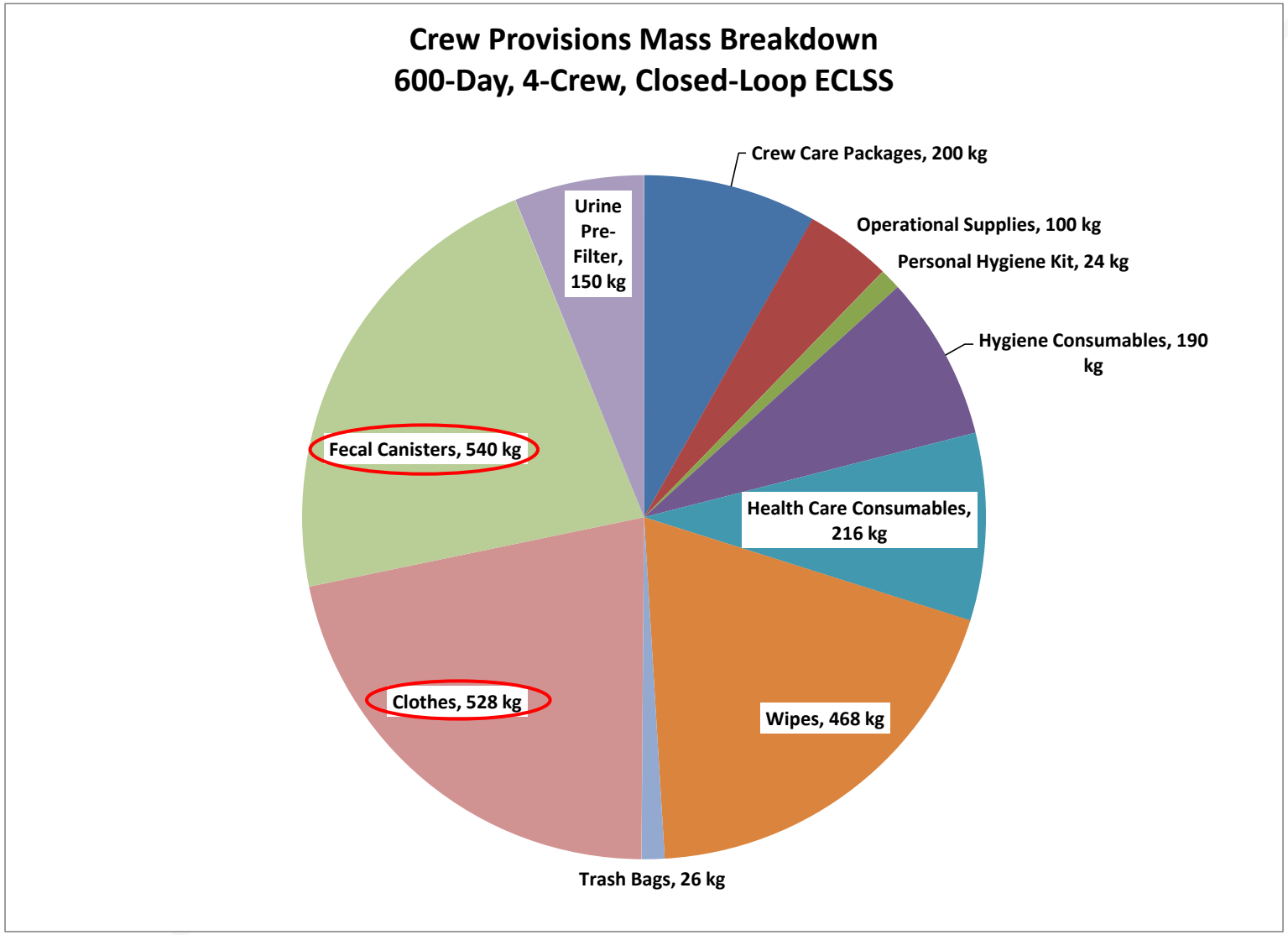
THREAT

Packing Density

- **Current study does not include storage efficiency for CTB arrangement/accessibility**
  - May increase CTB storage volume by as much as 30%

Crew Provisions Mass Breakdown

- **Driven by fecal canisters, clothes, and wipes**



Fecal Canisters (~540kg – 6% of total logistics)

OPPORTUNITY

- **Canisters consumption at 0.9kg/crewday**

- **Current missions assume that canisters are used to collect and store fecal waste**
- **Multiple crew-uses are stored in a single canister, which is removed periodically once full**
- **The canister is used to safely store the fecal waste after collection**

- **Processing waste instead of storing it in the original canister may be an opportunity to use fewer disposable canisters**
- **Dry waste would be safer to store in bags or other lightweight containers**

- **Assessment of other options should be pursued to determine optimal solution**

Clothes (~530kg – 6% of total logistics)

OPPORTUNITY

- **Current study assumes disposable clothes at 0.22 kg/crewday**
- **Laundry system could reduce clothing rate from 0.22 kg/crewday to 0.04 kg/crewday**
  - Results in mass savings of ~430kg for this case
  - Effect more significant with increased crew size and mission duration
- **However, laundry system would also increase system mass (laundry, water processing system)**
  - HAT study assumes 84kg laundry system and ~460kg mass increase in water processing system for 4-crew
  - Would result in mass increase for this case (600-day)
    - Mass savings possible for mission duration >756 days with 4-crew
- **Other laundry system designs (waterless, self-contained water processing, etc.) may result in mass savings at shorter mission durations**
- **Clothing rate could also be reduced via reusable clothing**
- **Integrated assessment of laundry/reusable clothing options should be pursued to determine optimal solution**

Other Opportunities/Threats

OPPORTUNITIES

Rodnik Tank/COPVs

- **Current study assumes use of Rodnik tanks for H_2O (35kg empty mass, 210L capacity) and COPVs for O_2 and N_2 (74.8kg empty mass, 38.1kg O_2/28.7kg N_2 capacity)**
- **Other containment options/tank redesign should be explored to optimize container mass/capacity**

THREATS

Water Quality

- **Long-duration missions could greatly affect quality of water**
- **Additional assets/functions may be required to monitor water quality**

Summary of Opportunities/Threats

- **Potential opportunities to reduce overall logistics mass have been identified**
  - CTBs and fecal canisters represent ideal candidates for optimization studies
  - Food
    - Rate reduction limited to ~0.3 kg/crewday via packaging optimization
  - Clothes
    - Addition of laundry system and/or reusable clothing to reduce clothing rate
    - Integrated impact needs to be assessed

- **Identified potential threats that could increase mass and/or volume**
  - **Need for freezers to address food expiration**
  - Packing density to account for efficiency in CTB arrangement/accessibility
  - Water quality could be an issue due to mission durations

Water

Water Usage

Item	Units	Rate	Open/ Closed ECLS	Notes
O_2 Generation	kg per crewday	1	Closed	Orion/CCDev
H_2O Drink	kg per crewday	2	Both	Orion/CCDev
H_2O Food Rehydration	kg per crewday	0.5	Both	Orion/CCDev
H_2O Medical	kg per crewday	0.05	Both	Orion/CCDev
H_2O Hygiene	kg per crewday	0.4	Both	Orion/CCDev
H_2O Flush	kg per day	0.25	Both	Orion/CCDev

Water Recovery (Closed Loop)

Item	Units	Rate	Percent Recoverable	Notes
Sabatier	kg per crewday	0.5	-	50% of O_2 loss
Crew Latent	kg per crewday	1.87	100	Orion/CCDev
Urine	kg per crewday	1.49	85	Orion/CCDev
Flush	kg per day	0.25	85	Orion/CCDev
H_2O Hygiene	kg per crewday	0.4	100	Carried by HAT
H_2O Medical	kg per crewday	0.05	100	Carried by HAT

Water Container

Item	Capacity (L)	Empty Mass (kg)	Volume (m^3)	Notes
Rodnik Tank	210	35	0.21	ISS Heritage

- **Water usage rate of 3.08 kg and 4.08 kg for open and closed-loop ECLSS, respectively**
- **Water recovery of 4.44 kg by combining CAT and HAT rates**
- **Rodnik tanks used for containment**

Gases

Gases

Item	Units	Rate	Open/ Closed ECLS	Notes
O_2 Metabolic	kg per crew/day	0.82	Open	Orion/CCDev
Swing Bed Ullage - O_2	kg per day	0	Open	Orion CO_2 removal not used
Swing Bed Ullage - N_2	kg per day	0	Open	Orion CO_2 removal not used
Cabin Air Leakage	kg per day	0.00454	O_2/N_2 for Open, N_2 for closed	Engr. Estimate; O_2 leakage covered via generation
Cabin Air Leakage – Orion	kg per day	0.00908	O_2/N_2 for Open, N_2 for closed	Orion; O_2 leakage covered via generation
N_2/O_2 Tank Ullage	kg per tank	0.5	Both	Orion/CCDev

Gas Container

Item	Capacity (kg)	Empty Mass (kg)	Volume (m^3)	Notes
COPV - O_2	38.1	74.8	0.39	ISS Heritage
COPV - N_2	28.7	74.8	0.39	ISS Heritage

- **O_2 consumption and O_2 leakage covered by O_2 generation on closed-loop**
- **COPV tanks used for containment**

Food/Crew Provisions

Food/Crew Provisions

Item	Units	Rate	Notes
Food	kg per crew/day	1.831	BVAD Table & ISS experience
Food Containment Bags	kg per kg food	0	Included above
Waste Collection - Fecal Canisters	kg per day	0.9	per JSC/EC, Orion values
Waste Collection - Urine Prefilter	kg per day	0.25	per JSC/EC, Orion values
Fecal/Urine Collection Bags (contingency)	kg per crewday	0	Reuse contingency waste collection capability in Orion
Personal Hygiene Kit	kg per crew	1.8	ISS value; used for every six months
Hygiene Consumables	kg per crewday	0.079	Match Orion WCS Supplies Value
Clothing (No Laundry)	kg per crewday	0.22	Recent ISS data
Recreation & Personal Stowage	kg per crew	25/50	25kg for up to 1yr; 50kg for more than 1 yr.
Wipes (housekeeping)	kg per crewday	0.195	AES trash team / ISS historical data
Trash Bags	kg per crewday	0.011	AES trash team / ISS historical data
Operational Supplies	kg per crew	20/25	20kg for up to 1yr; 25kg for more than 1 yr.
Survival kit	kg per crew	0	Reuse Orion Items
Sleep Accommodations	kg per crew	0	Reuse Orion Sleep Restraints
Health Care Consumables	kg per crewday	0.09	AES trash team / ISS historical data
Medical/Surgical/Dental	kg	0	Assume reuse items included in 62kg misc. kit on Orion or booked in dry mass
Emergency Breathing Apparatus	kg per crew	0	Reuse Orion Items

- **Personal stowage and operational supplies rates vary based on mission duration**

Food/Crew Provisions - Containment

Food/Crew Provisions Containment

Item	Units	Rate	Notes
CTB Mass, Empty	kg	1.56	ISS
CTB Mass Capacity	kg	11.44	ISS average experience
CTB Volume	m^3	0.053	ISS

- **Food/crew provisions carried in ISS Cargo Transfer Bags (CTBs)**

Total Mass/Volume Calculation (4-crew, 600-day, closed loop)

CONSUMABLES		
Item	**Total Requirement (kg)**	**Notes**
Oxygen	100.1	Represents **30-day margin** assuming open loop ECLSS; needs for 600-day mission duration provided by closed-loop ECLSS
Nitrogen	13.3	Leakage/ullage assuming Orion + 4 modules
Water	361.5	Represents **30-day margin** assuming open loop ECLSS; needs for 600-day mission duration provided by closed-loop ECLSS
Food	4394.4	1.831 kg per crew/day; BVAD Table & ISS experience
Personal Stowage	200	50kg per crew for missions longer than 365 days
Operational Supplies	100	25kg per crew for missions longer than 365 days
Personal Hygiene Kit	24	1.8kg per crew for every 180 days
Hygiene Consumables	189.6	0.079kg per crew/day; Orion WCS supplies value
Healthcare Consumables	216.0	0.09kg per crew/day; ISS historical data
Wipes	468.0	0.195kg per crew/day; ISS historical data
Trash Bags	26.4	0.011kg per crew/day; ISS historical data
Clothes	528.0	0.22kg per crew/day; ISS historical data
WC - fecal canisters	540.0	0.9kg per day; per JSC/EC, Orion values
WC - urine prefilter	150.0	0.25kg per day; per JSC/EC, Orion values
TOTAL CONSUMABLES	**7311.3**	**kg**

CARRIERS/CONTAINERS		
Item	**Total Requirement (kg)**	**Notes**
CTBs	934.4	385 CTBs required for food; 214 CTBs required for Crew Provisions, for total of 599 CTBs
Rodnik Tank	70	2 Rodnik tank at 35kg
O2 Tank	224.4	3 COPV at 74.8kg each
N2 Tank	74.8	1 COPV at 74.8kg
TOTAL CONTAINER MASS	**1303.6**	**kg**

TOTAL MASS	**8614.9**	**kg**	***Requires 3 LMs due to mass***
Cygnus Capability to EML2	**3206**	**kg**	

Volume Dry Cargo					
Case	**Usable Cargo Mass† (kg)**	**Customer Cargo Mass* (kg)**	**Single CTB Ave. Density (kg/CTBe)**	**Number of CTB Required****	**Volume Required (m^3)**
600 Day, 4 Crew	6836.4	7656.8	13	589	**31.22**

Volume of 1 CTB: *0.053*

† Does not include bag FSE + Foam

** 12% packing factor*

*** Some packing efficiency when combine "rounded up" food & CP*

Volume of Water Tanks			
Type of Tank	**Volume of One Tank (m^3)**	**Total Number of Tanks**	**Total Volume Required (m^3)**
Water	0.21	2	**0.42**

ISS NORS Tank Volume			
Gas Carrier	**Volume (m^3)**	**Total Number of Tanks**	**Total Tank Volume (m^3)**
COPV (O_2)	0.39	3	1.17
COPV (N_2)	0.39	1	0.39
			1.56

Total Volume	**33.20**	**m^3**	***Requires 2 LMs due to volume***
Cygnus Capability to EML2	**18.9**	**m^3**	

Notes:

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag

NORS Tanks pressurized at 6000 psi

Conclusion

- **Logistics mass required to support transit trip to Mars vicinity assuming crew of 4 and 600 days (round-trip duration) amounts to 8,614.9kg occupying 33.2m^3 of volume**
  - Includes 30-day O_2 and H_2O consumables margin for contingencies
  - Could be delivered on 3 LMs

- **Potential opportunities to reduce overall logistics mass have been identified**
  - Food, CTBs and fecal canisters

- **Identified potential threats that could increase mass and/or volume**
  - **Need for freezers to address food expiration**
  - Packing density to account for efficiency in CTB arrangement/accessibility
  - Water quality could be an issue due to mission durations

- **Further assessment on identified opportunities/threats is recommended**

Backup

Water

- **Assumptions**
  - Rodnik tanks within pressurized volume of Logistics Module
    - Major difference against ISS – Impacts to pressurized cargo volume
  - Silver biocide water with 3 year shelf life

- **Consumption (See figure on next two charts)**
  - Consistent with MPCV and CCDev exploration assumptions
    - Slightly more conservative
      - Deviation from ISS
        - » 2.2 L/Crewman/Day Drinking/Hygiene/Food
        - » No medical allowance
        - » 0.3 L/Crewman/Day Flush*
        - » 75% water recovery rate vs 85%

Open-Loop ECLSS

2.9 L	Drinking/Hygiene/Food →	Crew Latent	1.87 L
0.35 L	Metabolic Water →	Urine	1.49 L
0.50 L	Water in Food →	Feces Water	0.19 L
0.05 L	Medical →	Wet Trash	0.25 L
0.125 L	Flush † →	Flush	0.125 L
3.08 L	Resupplied Water	Water Lost	3.925 L
0.85 L	Unaccounted Water		

† 0.25 L Water once a day flush for 2 Crew

- ISS Assumes 0.3 L/flush/crew/day

- Does not take into account Payload water
  - ISS uses 1.27 L Resupply of which 0.82 L is recovered and 0.45 L is lost

Closed-Loop ECLSS

1.0 L Water for O_2 Generation →
2.9 L Drinking/Hygiene/Food →
0.35 L Metabolic Water →
0.50 L Water in Food →
0.05 L Medical →
0.125 L Flush† →

4.08 L Resupplied Water
0.85 L Unaccounted Water

H_2 and O_2 → 0.5 L
Sabatier → 0.5
Crew Latent → 1.87 L
Urine → 1.49 L
Feces Water → 0.19 L
Wet Trash → 0.25 L
Flush → 0.125 L

Recoverable Water 3.985 L
Water Lost 0.94 L

† 0.25 L Water once a day flush for 2 Crew
- ISS Assumes flush/crew/day

Added 0.40 L Hygiene and 0.05 L Medical to recoverable water as recommended by DSH

- Does not take into account Payload water
  - ISS uses 1.27 L Resupply of which 0.82 L is recovered and 0.45 L is lost

Water (600 Day – Closed Loop)

600 Day Water Consumption			
Water Use	**Crew Daily Rate (kg/Crew/Day)**	**Total Crew Rate (kg/day)**	**Total Usage (kg)**
Drinking, Food Rehydration, Hygiene	2.9	11.6	7308
Medical	0.05	0.2	126
Flush	0.063	0.25	157.5
O_2 Generation	1	4	2520
		Total	**10111.5**

611 Day Water Supply				
Water Recovery	**Recoverable Water (kg/Crew/Day)**	**Recovered Water (kg/Crew/Day)**	**Total Crew Recovery Rate (kg/Day)**	**Total Recovery (kg)**
Crew Latent (100%)	1.87	1.87	7.48	4712.4
Urine (85%)	1.49	1.27	5.07	3191.6
Flush (85%)	0.125	0.05	0.21	133.9
Sabatier (50% of O_2 loss)	0.5	0.50	2.00	1260.0
Hygiene (100%)	0.4	0.40	1.60	1008.0
Medical (100%)	0.05	0.05	0.20	126.0
			Total	**10431.9**
0.0	**kg delta of water results in**	**0**	**total number of tanks required**	

Water (30 Day Margin – Open Loop)

30 Day Water Consumption (Margin)			
Water Use	**Crew Daily Rate (kg/Crew/Day)**	**Total Crew Rate (kg/day)**	**Total Usage (kg)**
Drinking, Food Rehydration, Hygiene	2.9	11.6	348
Medical	0.05	0.2	6
Flush	0.063	0.25	7.5
		Total	**361.5**

361.5kg delta of water results in 2 total number of tanks required

Carrier Mass			
Water Carrier	**Empty Mass (kg)**	**Number of Tanks**	**Total Mission Mass (kg)**
Rodnik Tank	35	2	70

Carrier Volume			
Water Carrier	**Amount of Water (L)**	**Volume of Tank (m^3)**	**Volume of All Tanks (m^3)**
Rodnik Tank	210	0.21	0.42

Gases

- **Assumptions**
  - Provide N_2 and O_2 to cover leakage
    - No oxygen required for crew consumption for closed-loop cases, created using water via O_2 generator
  - COPV (ISS NORS Tank) inside pressurized volume – impacts cargo volume
    - Empty mass of 74.8kg; capacity of 38.1kg O_2 or 28.7kg N_2
  - Calculated leak rate based on ISS Engineering experience, and considers:
    - Nominal and anomalous leakage
  - Includes tank ullage (closed-loop and open-loop)

- **Consumption**
  - O2 crew consumption rate of 0.82 kg/crew/day for 30-days contingency (open-loop)
  - Air Leakage estimated rate of 0.01 lbm/day (0.0045 kg/day) for a given module
    - Engineering estimate*
    - Little over double for Orion (0.00908 kg/day)
  - For leakage calculations assume:
    - MPCV + 4 modules (Node, Deep Space, and two Logistics Modules) for 600-day mission

* ***Leakage Rate Estimation***
  - *Based upon ISS Node 1 specification (.117 lb/day) and test (.005 lb/day) leak rates*
  - *Doubling test rate but still stay order magnitude below requirement*
    - *Try not to be so conservative you can't verify*

Gases – Crew Consumption

- **Tank provided oxygen for crew consumption for open-loop ECLSS only**
  - Oxygen created using water for closed loop
- **Required for 30-day margin only**

Gas	Crew Daily Rate (kg)	Total Crew Rate (kg)	30 day usage (kg)
Oxygen	0.82	3.28	98.4

Gases – Leakage

- **N_2 for leakage and ullage makeup for entire mission duration; O_2 for 30-day margin only**
  - Orion + 4 modules for 600-day mission
  - O_2 for actual mission duration covered via O_2 generator
  - ISS utilizes air vs Nitrogen – Easier process and cost less

Gas	Daily Leakage Orion (kg)	Daily Leakage 4 Modules (kg)	Total Daily Leakage (kg)	Total Mission Leakage (kg)*
Oxygen	0.00191	0.00378	0.00569	**0.17**
Nitrogen	0.00717	0.01422	0.02139	**12.83**

**Oxygen generator on; O2 value represents margin*

Gases – Ullage (Open Loop)

- **Gas tank ullage**
  - Dependent on the number of days

Tank Ullage	Ullage per Tank (kg)**	Total Number of Tanks	Total Ullage (kg)
Oxygen	0.50	3	1.5
Nitrogen	0.50	1	0.50

* Provided by Exploration Logistics Team

** ISS NORS value

Gasses (Quantity and Mass)

- **Number of tanks driven by crew consumption, leakage, and ullage**

Gas Carrier	Empty Mass (kg)	Total Number of Tanks	Total Tank Mass (kg)
COPV (Oxygen)	74.8	3	224.4
COPV (Nitrogen)	74.8	1	74.8

Food

- **Assumptions**
  - Only use “single” CTB* for containment/storage

- **Mass per crewmember per day**
  - 1.831 kg for food, including sealed wrapping
    - Does not include Bulk Overwrap Bag (BOB) weight
      - ~60 grams each
    - Does not include containment/storage container
      - CTB weight factored in separately
        - » Single CTB + foam = 1.56 kg

*Conservative bag choice

Food

- **Food totals are just the food and its wrapper**

	Crew Daily Rate (kg)	Total Crew Rate (kg)	Usage Total (kg)
Rehydratable Food w/wrapper	1.831	7.324	4394.40

Containment Bag	Empty Mass (kg)	Total Number of CTBs	Total CTB Mass (kg)
Single CTB	1.56	385	600.6

*1 CTB holds ~11.44 kg usable cargo

Crew Provisions

- **Assumptions**
  - Provide clothes, comfort items, office supplies, waste and hygiene supplies, etc. for crew
  - Three categories
    - Per mission use (kg/crew)
    - Daily use per crew person (kg/crew/day)
    - Daily use for all crew (kg/day)

Per Mission Use (kg)				
Category	**Subcategory**	**Examples**	**Mission Mass Per Crewmember (kg/Crew)**	**600 Day, 4 Crew Total (kg)**
Crew Personal Items, One-time use, and Crew care Packages	Crew Care Packages	Personal photos, personal T-shirts, books, keepsakes, Shoes, etc.	25/50*	200
	Operational Supplies	Batteries, notebooks, office supplies, etc.	20/25*	100
	Personal Hygiene Kit		1.8**	24
		Total		**324.0**

* Usage for missions less than/greater than 365 days

** 1.8 kg/crew for every 180 days

Crew Provisions

- **Some notable differences between ISS and Exploration modeling**
  - ISS model uses 0.153 kg/c/d for wipes
  - ISS model uses 0.196 kg/c/d for clothing

Daily Use per Crew Person (kg/crew/day)				
Category	**Subcategory**	**Examples**	**Mass Per Crewmember per day (kg/C/D)**	**600 Day, 4 Crew Total (kg)**
Regularly consumed items	Hygiene consumables		0.079	189.6
	Health Care Consumables		0.09	216
	Wipes	Wet wipes, Household wipes, dry wipes	0.195	468
	Trash Bags		0.011	26.4
	Clothes	t-shirts, shorts, pants, socks, exercise clothes, etc.	0.22	528
		Total	0.595	**1428**

Crew Provisions

- **Fecal canisters and urine pre-filter differ by toilet design from ISS**
  - ISS model uses KTOs at 0.48 kg/d
  - Urine pre-treat filter considered part of ISS WHC

Daily Use for All Crew (kg/day)				
Category	**Subcategory**	**Examples**	**Mass Per Day (kg/Day)**	**600 Day, 4 Crew Total (kg)**
Waste Collection	Fecal Canisters		0.90	540
	Urine Pre-filter		0.25	150
		Total	1.15	**690**

Crew Provisions

- **Summary of all Crew provisions**

Crew Provision Category	Total Usage (kg)
Mission Use	324.0
Daily Use per Crew	1428
Daily Use for All Crew	690
Total	2442.0

Containment Bag	Empty Mass (kg)	Total CTBs	Total Mass (kg)
Single CTB	1.56	214	333.84

- **Single CTB ~ 11.44 kg usable cargo**
  - Bag + Foam = 1.56 kg

Total Mass Calculation

Daily Use Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Water	361.5	Represents margin on mission duration
Oxygen (Metabolic)	98.4	Represents margin on mission duration
Oxygen (Leakage & Ullage)	1.67	Represents margin on mission duration
Nitrogen (Leakage & Ullage)	13.33	Possibly more efficient to fully load tank with air or N_2 and balance oxygen for proper partial pressures
Food	4394.4	
Crew Provisions	2118	
Total	**6987.3**	

Per Mission Mass Totals		
Consumable/Carrier	**Total Requirement (kg)**	**Notes**
Rodnik Tanks (2)	70	Each Rodnik is ~35 kg
O_2 Tanks (3)	224.4	Each empty O_2 & N2 COPV is ~ 74.8 kg
N_2 Tanks (1)	74.8	Each empty O_2 & N2 COPV is ~ 74.8 kg
Crew Provisions	324.0	Possible to gain efficiency by using larger bag (i.e. double CTB or M0 bag)
CTB Mass	934.4	
Total	**1627.6**	

Grand Total = **8614.9** **kg**

Total Volume Calculation

- **Assumptions**
  - Apply single CTB for conservatism and simplicity
    - Final packing efficiencies could be obtained
  - ISS average density from historical experience
  - Volume of 1 CTB = 0.053 m^3
  - Single CTB average packing density is 13 kg/CTBe

- **ISS packing experience defines "Customer Cargo"**
  - Customer cargo = (Usable Cargo) x (Packing Factor)
    - Usable cargo is the weight of the cargo item alone, no packing or FSE
    - ISS Packing factor = 12%

Volume Calculation

Volume Dry Cargo					
Case	Usable Cargo Mass† (kg)	Customer Cargo Mass* (kg)	Single CTB Ave. Density (kg/CTBe)	Number of CTB Required**	Volume Required (m^3)
600 Day, 4 Crew	6836.4	7656.8	13	589	**31.22**

† Does not include bag FSE + Foam
* 12% packing factor
** Some packing efficiency when combine "rounded up" food & CP

Volume of 1 CTB: 0.053

Volume of Water Tanks			
Type of Tank	Volume of One Tank (m^3)	Total Number Tanks	Total Volume Required (m^3)
Water	0.210	2	0.42

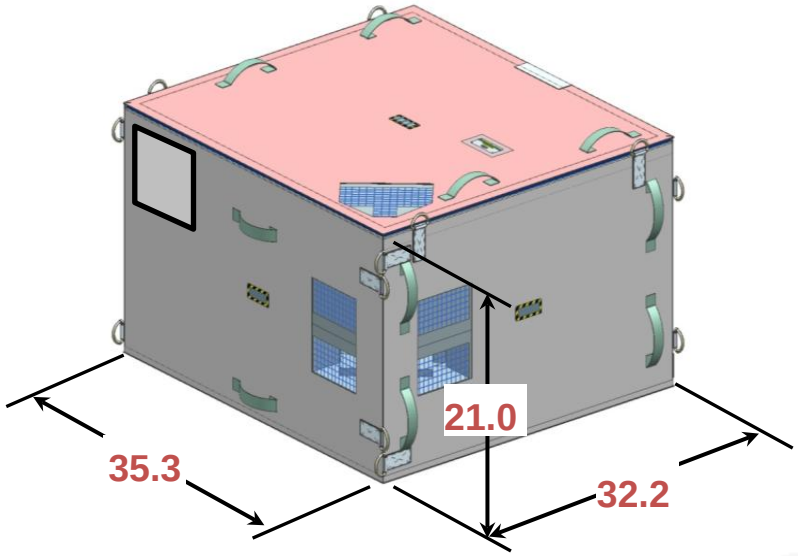
ISS NORS Tank Volume			
Gas Carrier	Volume (m^3)	Total Number of Tanks	Total Tank Volume (m^3)
COPV (O_2)	0.39	3	1.17
COPV (N_2)	0.39	1	0.39
			1.56

NORS Tanks fly up in FSE that take up volume equivalent to an M-01 bag
NORS Tanks pressurized at 6000 psi

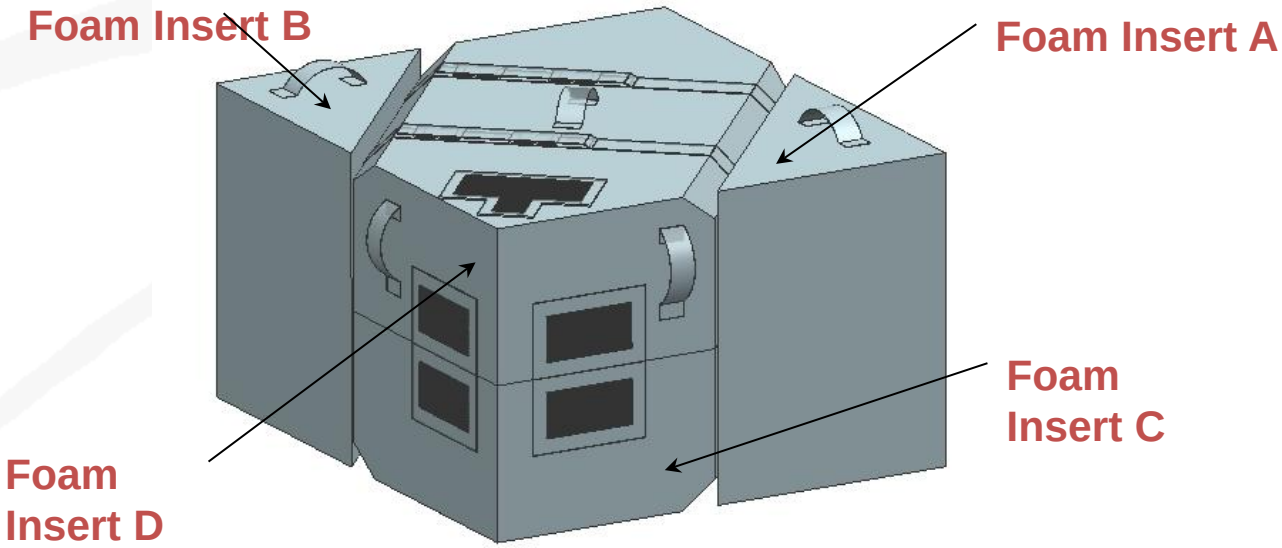
Total Volume	**33.20**	**m^3**

Backup for Consumable

M-01 Configuration

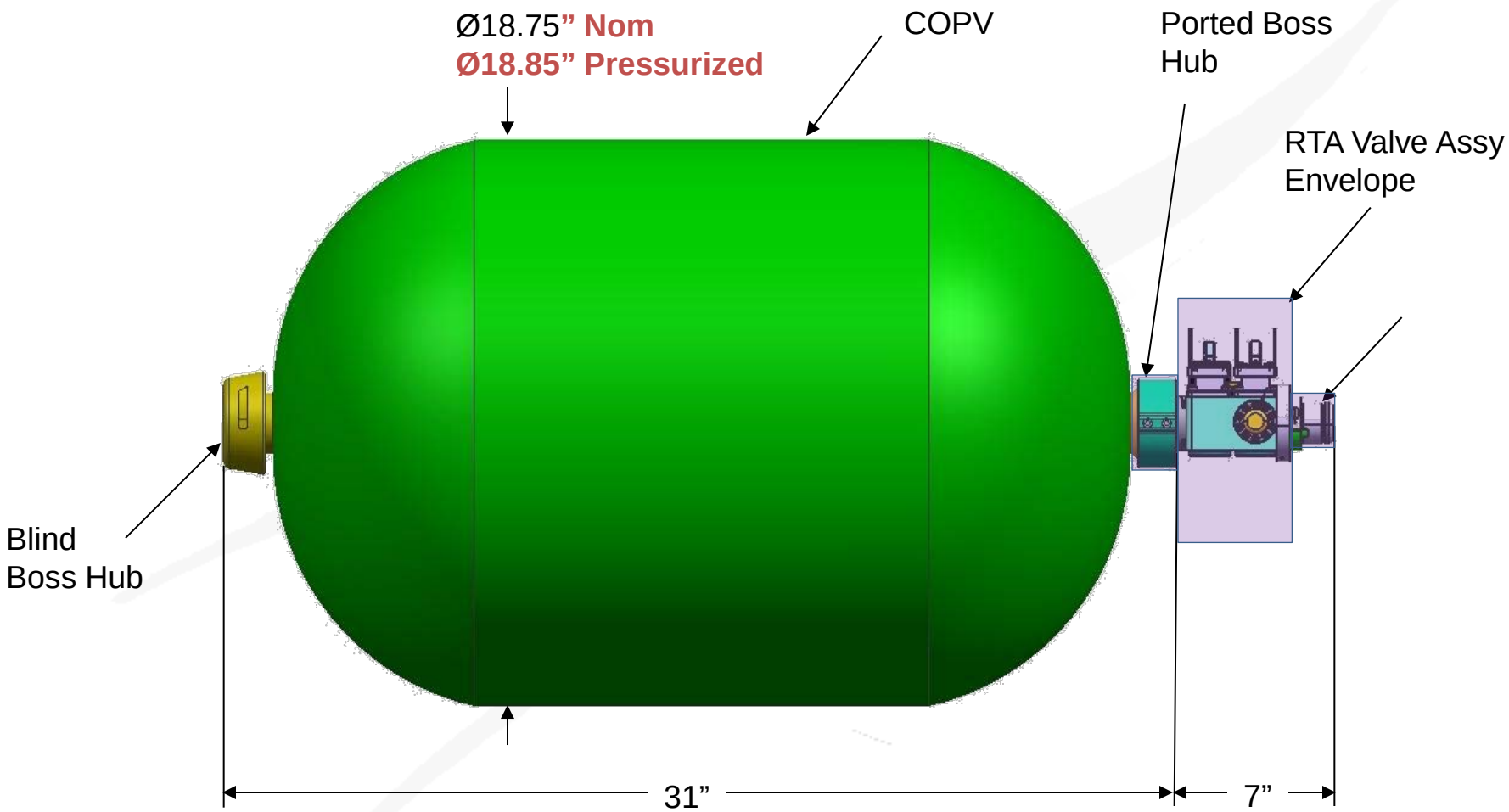


- Uses M-01 Bag dimensional envelope
- Same basic interfaces as M-01 bag
- Same zippered opening as M-01 bag
- Incorporates venting for excess gas buildup
- Utilizes cut Zotek F-30 foam inserts
- Center foam section can fit through tight diameter hatches
- Inserts wrapped in Beta Cloth to eliminate debris
- P/N 684-015302



Foam Inserts – VIA Not shown

RTA Dimensions



ISS Trash/Waste

- **Assumptions**
  - Account for Crew daily waste, Fecal waste, hardware, and packing material
  - Trash stored in CTBs, Jettison Stowage Bags (JSB), and KTOs
  - Whatever went up, must come down
    - Except for urine and condensate (Vented)
    - Rate equivalent to usage

- **Mass capacity for waste containers**
  - CTB = (Depends on available CTB size)
  - KTO = 11.5 kg
  - JSB = variable depending on content (i.e. H/W vs bubble wrap)
    - Range from 0.5kg to 20 kg

- **Volume capacity for waste containers**
  - Single CTB* = 0.0283 m^3
  - KTO = 0.0198 m^3
  - JSB = 0.0764 m^3

*Varies by chosen CTB